RANGE SAFETY GROUP

STANDARD 321-02

COMMON RISK CRITERIA FOR NATIONAL TEST RANGES

SUBTITLE: INERT DEBRIS

WHITE SANDS MISSILE RANGE
REAGAN TEST SITE
YUMA PROVING GROUND
DUGWAY PROVING GROUND
ABERDEEN TEST CENTER
NATIONAL TRAINING CENTER

ATLANTIC FLEET WEAPONS TRAINING FACILITY
NAVAL AIR WARFARE CENTER WEAPONS DIVISION
NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
NAVAL UNDERSEA WARFARE CENTER DIVISION, NEWPORT
PACIFIC MISSILE RANGE FACILITY
NAVAL UNDERSEA WARFARE CENTER DIVISION, KEYPORT
NAVAL STRIKE AND AIR WARFARE CENTER

30TH SPACE WING
45TH SPACE WING
AIR FORCE FLIGHT TEST CENTER
AIR ARMAMENT CENTER
AIR WARFARE CENTER
ARNOLD ENGINEERING DEVELOPMENT CENTER
GOLDWATER RANGE
UTAH TEST AND TRAINING RANGE

NEVADA TEST SITE

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GLOSSARY

ACRONYMS

DOD	Department of Defense
E_F	expected fatality
FAA	Federal Aviation Administration
HTS	Hazard Tracking System
IAW	in accordance with
kg	kilogram
MRTFB	Major Range and Test Facility Base
NASA	National Aeronautics and Space Administration
P_F	probability of fatality
P_I	probability of impact
RAC	risk assessment code
RALCT	Risk and Lethality Commonality Team
RCC	Range Commanders Council
RSG	Range Safety Group
USSPACECOM	U.S. Space Command

FOREWORD

Planned and unplanned debris generated by flight tests and space launches present a safety concern for all ranges. Each range has established its own set of criteria and analytical methods for protecting personnel, facilities, aircraft, and other assets from such debris. Although these separate efforts have been very successful, the logical relationships between criteria used at separate ranges and across different hazards are often not clear. Common risk criteria can simplify scheduling and reduce cost for users of multiple ranges.

The Risk And Lethality Commonality Team (RALCT) was formed as a Range Commanders Council (RCC) Range Safety Group (RSG) task team in February 1996 for the purpose of reaching a consensus on reasonable common standards for debris protection criteria and analytical methods. Team members include the following:

Council Members and Associates

45th Space Wing
Air Force Flight Test Center
Air Force Development Test Center
U.S. Army Kwajalein Atoll/ Missile Range
Naval Air Warfare Center Weapons Division
NASA Wallops Flight Facility
30th Space Wing
White Sands Missile Range

Supporting Organizations

ACTA, Inc.
APT Research, Inc.
FAA-Associate Administrator for Commercial Space Transportation
Sandia National Laboratories
U.S. Army Test & Evaluation Command
TYBRIN Corporation
U.S. Army Space and Strategic Defense Command

This document represents the cooperative effort of the above organizations to define and develop a common approach for assessing debris lethality and risk. It addresses general policy regarding containment of debris and risk acceptance, as well as specific policies and criteria for personnel, aircraft, ships, and spacecraft.

This document consists of a basic volume, which defines the criteria, and a supplement for use by the safety organizations.

CHAPTER 1

INTRODUCTION

1.1 Purpose

This document provides a common set of debris protection policies, risk criteria, and guidelines to protect personnel and assets during manned and unmanned flight operations. It establishes the following:

1. Maximum risk criteria for both the general public (involuntary acceptance) and mission essential personnel (voluntary acceptance)
2. Debris lethality criteria for unprotected and sheltered personnel
3. Debris damage thresholds for aircraft and ships

1.2 Scope

The policies and criteria in this document are intended for use by DOD national ranges and Major Range and Test Facility Bases (MRTFB). These policies and criteria apply to debris generated by endoatmospheric and exoatmospheric missile intercepts, aeronautical system testing, ballistic missiles, anti-satellite missiles, air-to-air missiles, surface-to-air missiles, air-to-surface missiles, cruise missiles, space launch vehicles, and unmanned aircraft. They are not intended to apply to debris generated by training operations or orbiting spacecraft other than targets.

1.3 Responsibilities

DOD Directive 3200.11 assigns responsibility to the Range Commander for protection within established limits. A basis for establishing the risk limits is provided herein. Therefore, the Range Commander will ensure that all missions are conducted safely, consistent with operational requirements. He will:

1. Consider the risks in comparison to the operational requirements and national need
2. Authorize risk management procedures, in lieu of hazard containment, when warranted by operational requirements
3. Accept risks greater than the criteria herein only when warranted by operational needs. This should be documented well in advance of the mission

The range will:

1. Establish practices and methods to evaluate risks from all range operations, and ensure that risks are accepted at the appropriate authority level
2. Maintain records of documented waivers to the risk criteria
3. Coordinate with other ranges to clearly document safety responsibility for all planned and unplanned debris that may result from missions involving more than one range

1.4 Waiver Requirements

Within this document, mandatory requirements use the word "shall" and must be met or waived. Advisory requirements use the words "should" and "may" and need review by the cognizant safety official but do not require a waiver. A record of waivers should be maintained by the range to assure that an informed decision was accomplished as part of the risk management process.

CHAPTER 2

POLICIES AND PROCEDURES

2.1 Policy

As a general policy, safety will be maximized consistent with operational requirements. All ranges strive to achieve complete containment of debris resulting from normal and malfunctioning flights. However, if the planned mission cannot be accomplished under these conditions, a risk management policy may be used if authorized by the Range Commander or his designated representative.

2.1.1 General Public. The general public, which includes all range personnel not essential to a specific mission, will be protected to an individual and collective risk significantly less than the average public exposure. Personnel on aircraft, ships, oil rigs, offshore platforms, and in other facilities will be protected to the same level, with added protection to avert catastrophic consequences to aircraft and ships.

2.1.2 Mission Essential Personnel. A certain degree of risk is inherent to hazardous operations. Mission essential personnel will not be exposed, individually and collectively, to a risk level greater than comparable high-risk occupations. Personnel in aircraft, on ships, oil rigs, and offshore platforms, and within other facilities will be protected to the same level, with added protection to avert catastrophic consequences to aircraft and ships.

2.1.3 Spacecraft. Orbiting manned spacecraft will be protected to a level greater than that provided to mission essential aircraft. Ranges should coordinate with the U.S. Space Command (USSPACECOM), as required, when planned missions involve vehicles or debris with altitude capability greater than 100 km.

2.1.4 Environment. Debris issues will be considered and mitigated as necessary, as part of the environmental documentation.

2.2 Risk Management

Risk management is a systematic and logical process to identify and control hazards. This process includes any or all of the following steps: 1) identify the hazards, 2) define hazard levels, 3) define risks, 4) define and implement risk reduction measures, 5) obtain approval from proper authority, and 6) ultimately accept the hazard or risk. Each step is described below.

Probabilistic calculations of risk should be made using methods consistent with the principles presented in the supplement. Tools consistent with system safety principles may also be used to evaluate the risk, since the overall system safety process follows the same basic steps as the risk management process defined here. This includes such tools as Hazard Tracking Systems (HTS) and Risk Assessment Code (RAC) Matrices IAW MIL-STD-882C.

2.2.1 Identify the Hazards. Potential hazard sources are examined by evaluating the system to be flown and the range safety constraints. Information sources include: range safety data packages, system description documents, mission essential personnel locations, surrounding population data, the range safety system used, and lessons learned on similar missions.

2.2.2 Define Hazard Levels. Hazard levels are defined using qualitative and quantitative methods. This step produces basic measures of the associated debris hazards including fragment size, density, mass, and energy. In some cases, this step will provide sufficient information to support the decision-making process without further analyses.

2.2.3 Define Risks. Risks are defined using qualitative and quantitative methods to assess and compare the hazard level to the vulnerability of the protected asset (personnel, facility, or others). This assessment produces risk measures including individual probability of fatality (P_F) and expected number of fatalities (E_F). This step provides information needed to determine whether further risk reduction measures are warranted.

2.2.4 Define and Implement Risk Reduction Measures. If the risk is initially unacceptable, various protective measures should be considered to eliminate, mitigate, or control the risks. Elimination is achieved by design or system changes which remove the hazard source. Mitigation is achieved by reducing the hazard level or the effect of the hazard. Control is achieved by using flight termination systems, containment policies, evacuation, sheltering, and other measures to protect assets from the hazards. Implementation of these measures may warrant a reassessment of the risk using revised assumptions.

2.2.5 Obtain Approval from Proper Authority. Each organization should establish and use procedures which assure that risk levels are reviewed at the proper level of authority. This review should compare the operational risk to the criteria defined in this document and other applicable mission requirements. In general, higher-risk operations require a higher level of approval.

2.2.6 Accept the Risk. The final and mandatory step in risk management is the acceptance of operational risks by a properly informed authority. In general, this acceptance should be documented using existing procedures. These procedures should include means of ensuring that the standards and controls are being implemented.

CHAPTER 3

CRITERIA

This chapter defines criteria to protect personnel, aircraft, ships, and spacecraft from potentially lethal debris. Definition of such debris for personnel, aircraft, and ships is provided in the appendix.

3.1 Personnel Protection

3.1.1 General Public.

3.1.1.1 Individual Risk Criteria. Individuals shall not be exposed to a probability of fatality greater than 1E-7 for any single mission and 1E-6 on an annual basis (see table 3-1).

3.1.1.2 Collective Risk Criteria. Collective risk for the general public shall not exceed an expected number of fatalities of 3E-5 for any single mission. Annual collective risk for the general public should not exceed an expected number of fatalities of 1E-3.

3.1.2 Mission Essential Personnel.

3.1.2.1 Individual Risk Criteria. Individual mission essential personnel shall not be exposed to a probability of fatality greater than 3E-6 for any single mission. Annual individual risk for mission essential personnel should not exceed 3E-5.

3.1.2.2 Collective Risk Criteria. Collective risk for mission essential personnel shall not exceed an expected number of fatalities of 3E-4 for any single mission. Annual collective risk for mission essential personnel should not exceed an expected number of fatalities of 1E-2.

3.2 Aircraft Protection

3.2.1 Non-Mission Aircraft Criteria.

Hazard volumes are defined for those regions of the atmosphere in which debris capable of causing a fatal accident is predicted. Non-mission aircraft shall be permitted to fly only through airspace where the probability of an impact from such debris does not exceed 1E-7.

3.2.2 Mission Essential Aircraft Criteria.

Hazard volumes are defined for those regions of the atmosphere through which debris capable of causing a fatal accident is predicted (see appendix). Mission essential aircraft shall be permitted to fly only through airspace where the probability of an impact from such debris does not exceed 1E-6.

3.3 Ship Protection

The term "ship" includes boats and watercraft of all sizes.

3.3.1 Non-Mission Ship Criteria.

3.3.1.1 Personnel on non-mission ships shall not be exposed to an individual probability of fatality greater than 1E-7 per mission. In addition, the collective risk (expected number of fatalities) shall not exceed 3E-5 per mission.

3.3.1.2 Hazard areas are defined for those regions of the ocean upon which debris capable of causing a catastrophic accident is predicted. Ships shall be precluded from passing through those areas where the probability of an impact from such debris exceeds 1E-6.

3.3.2 Mission Essential Ship Criteria.

3.3.2.1 Personnel on mission essential ships shall not be exposed to an individual probability of fatality greater than 3E-6 per mission. In addition, the collective risk (expected number of fatalities) shall not exceed 3E-4 per mission.

3.3.2.2 Hazard areas are defined for those regions of the ocean upon which debris capable of causing a catastrophic accident is predicted. Mission essential ships shall be precluded from passing through those areas where the probability of impact from such debris exceeds 1E-5.

3.4 Spacecraft Protection

Manned or mannable spacecraft shall be protected by: (1) ensuring a spherical miss distance of 200 km, or (2) not exceeding a probability of impact greater than 1E-7 with 1 mm or larger debris. Either approach is applied from launch through impact or orbital insertion. For this standard, orbital insertion is defined as the time at which a vehicle achieves a state vector that produces at least one revolution.

3.5 Criteria Summary

Table 3-1 below summarizes the criteria defined by this document. All of the criteria are mandatory requirements except those highlighted by an asterisk,which are advisory requirements.

TABLE 3-1
SUMMARY OF COMMONALITY CRITERIA

Max. Acceptable Probability	Undesired Event	Duration
1E-7	Individual Fatality (General Public)	One Mission
1E-6	Individual Fatality (General Public)	One Year
3E-5	Total Fatalities (General Public)	One Mission
1E-3*	Total Fatalities (General Public)	One Year
3E-6	Individual Fatality (Mission Essential)	One Mission
3E-5	Individual Fatality (Mission Essential)	One Year
3E-4*	Total Fatalities (Mission Essential)	One Mission
1E-2*	Total Fatalities (Mission Essential)	One Year
1E-7	Non-Mission Aircraft	One Mission
1E-6	Mission Essential Aircraft	One Mission
1E-6	Non-Mission Ships	One Mission
1E-5	Mission Essential Ships	One Mission
1E-7	Manned/ Mannable Spacecraft	One Revolution

* Advisory Requirements

APPENDIX A

HAZARDOUS DEBRIS DEFINITION

1.0 Introduction

This appendix provides data to assist in applying the criteria defined in Chapter 3. The appendix includes:

1. Debris fragment injury and death hazards to personnel
2. Minimum size debris hazardous to aircraft
3. Minimum size debris hazardous to ships and boats

Each of these definitions is considered a conservative "best estimate" recognizing considerable uncertainty. They are applied to generic assets (personnel, aircraft, ships) and should be used in the absence of other data. Where specific data on asset vulnerability are available, more precise calculation may be used. A more detailed discussion of the derivation of these data is provided in Chapter 4 of the supplement to this standard.

2.0 Debris Hazards to Personnel

The personnel protection criteria are defined in Chapter 3, paragraph 3.1, on a probabilistic basis. To apply these criteria, additional data are needed. Figure A-1 presents a curve which relates debris impact kinetic energy to the probability of fatality. It results from averaging body position data assuming that equal numbers of the exposed population are standing, sitting, and prone, and also accounts for the body area exposed by each position. This average data can be used when there is no knowledge of the likely body positions. If additional data relating to standing, sitting, and prone are available, an appropriate average can be generated. The curves for each position are provided in the supplement.

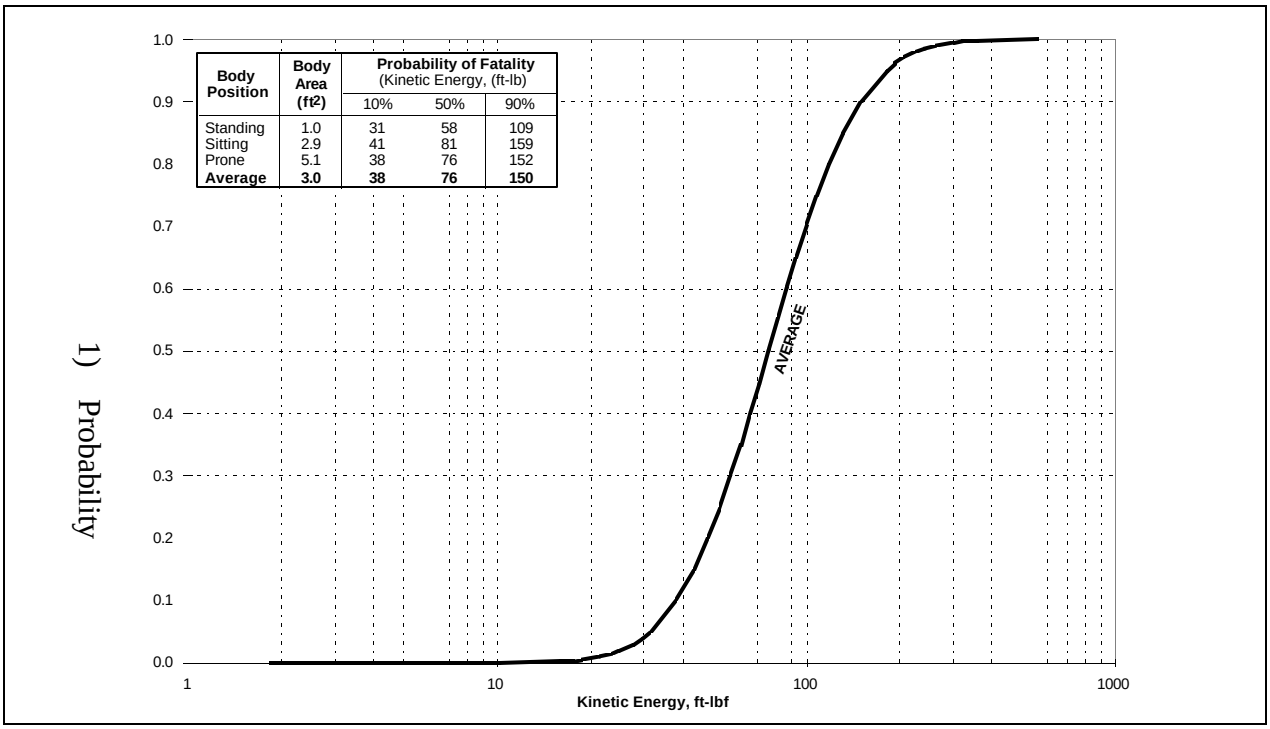

Figure A-1. Probability of Fatality from Debris Impacts.

To calculate the probability of fatality from impact of debris with a given kinetic energy, multiply the probability of impact by the probability of fatality from Figure A-1. The probability of impact is a function of the amount and size of the debris and the area of the person.

Injury curves derived from the Lewis skin penetration equation for debris fragment impact kinetic energy vs. probability of skin penetration are shown at Figure A-2. The different curves are applicable to fragments of varying impact surface areas (expressed in cm^2, i.e., the amount of surface area of the debris fragment actually striking a person.) As with the fatality curves, average body position data is used with the assumption of equal numbers of the exposed population standing, sitting, and prone; also, body area exposed by each position is accounted for. The Lewis equation and its usage are presented at chapter 4, paragraph 1 of the supplement to this standard. (See also the Kokinakis Skin Penetration equation at chapter 4, paragraph 1 of the standard; it defines the minimum velocity required for a fragment to penetrate the skin.)

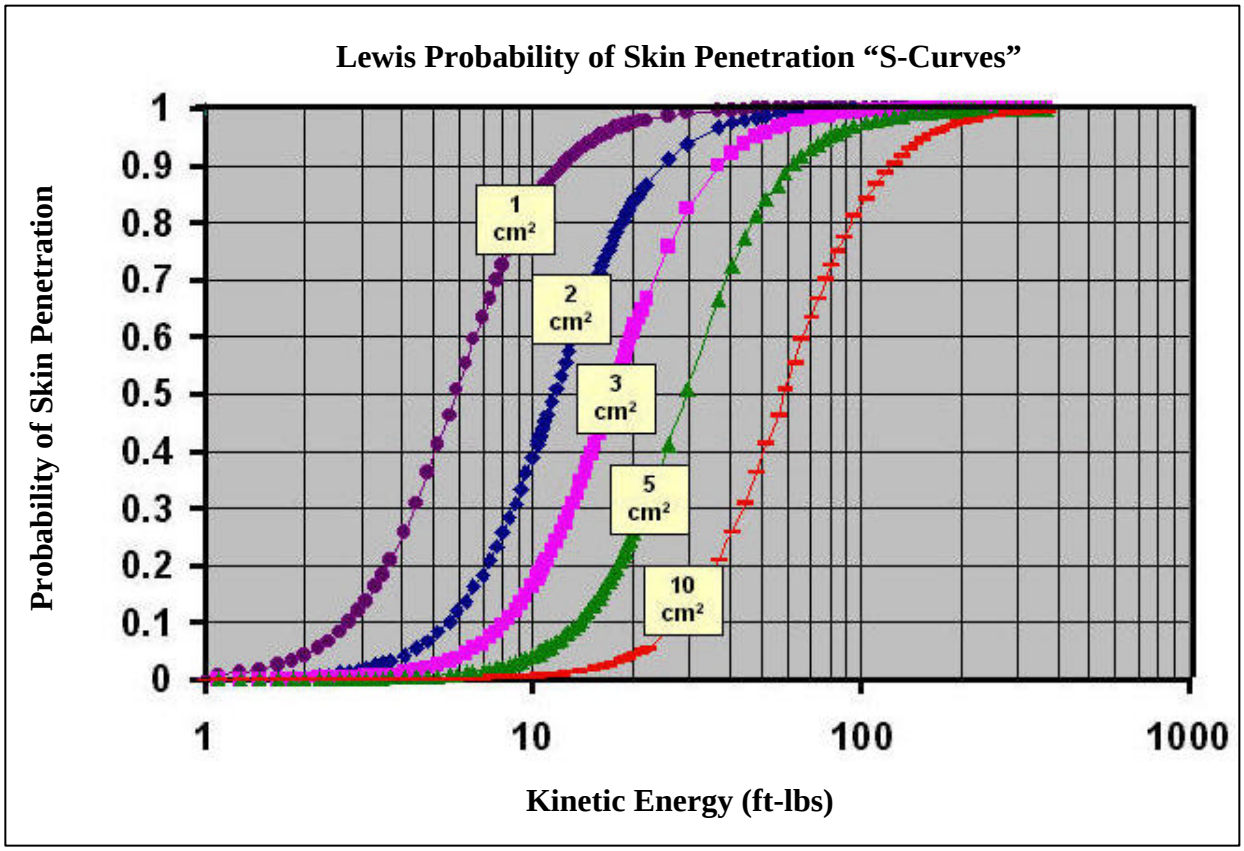

Figure A-2. Lewis Equation Skin Penetration Injury "S-Curves."

The curves derived from the Cooper blunt trauma equations for debris fragment diameter vs. kinetic energy are shown at Figure A-3. The different curves are applicable to the different sizes (expressed in kg) of persons being struck by the fragments. Average body position data is used with the assumption of equal numbers of the exposed population standing, sitting, and prone; also, body area exposed by each position is accounted for. The Cooper equations and usage are presented at chapter 4, paragraph 1 of the supplement to this standard.

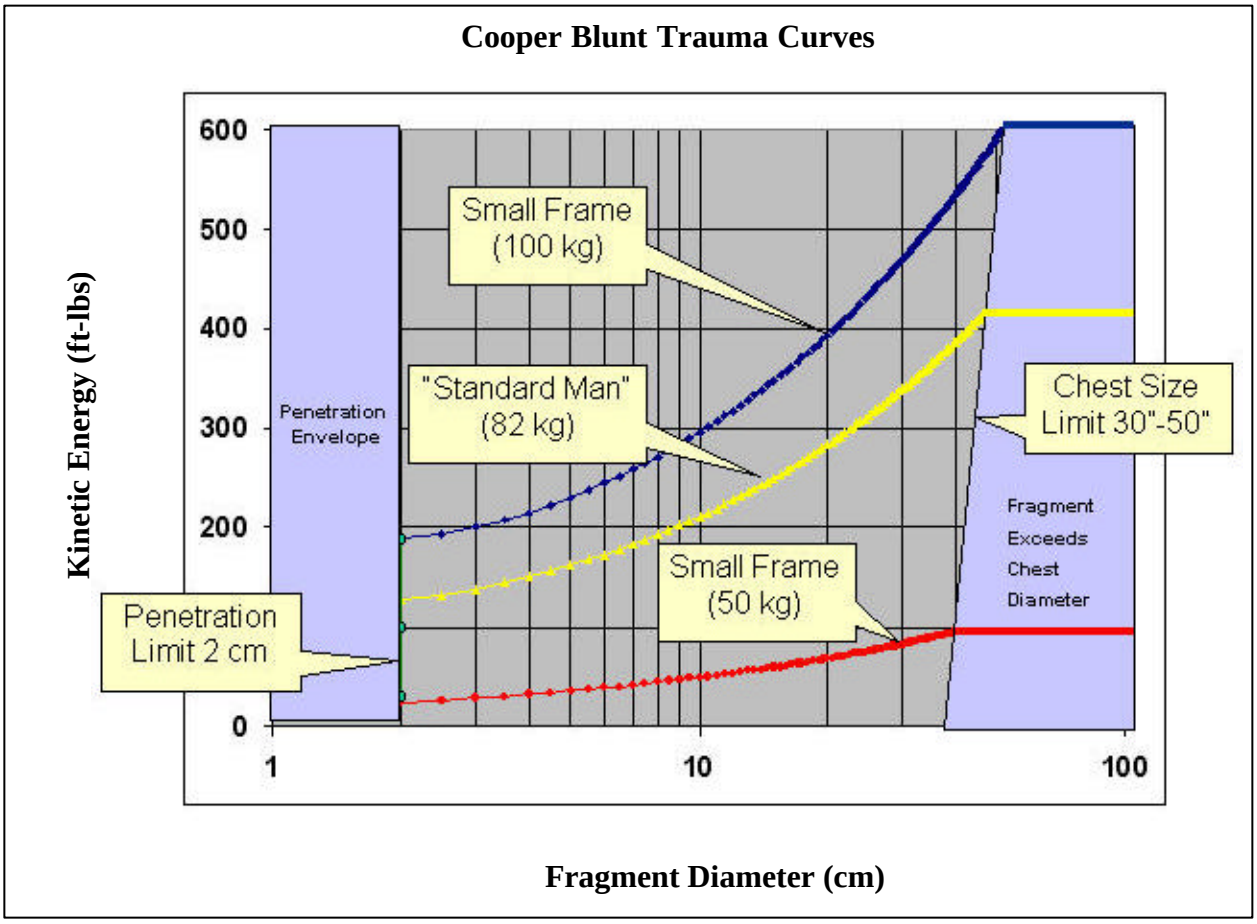

Figure A-3. Cooper Blunt Trauma Injury Curves.

3.0 Debris Hazards to Aircraft

A debris fragment is considered to be potentially lethal to an aircraft if it is capable of producing sufficient damage to cause loss of life or necessitate emergency response by the crew to avoid a catastrophic consequence. The two ways that debris can be hazardous to aircraft are: (1) fragment penetration of a critical aircraft structure or the windshield, and (2) fragment ingestion by an engine. Table A-1 provides standardized information for the smallest debris mass needed to produce these events.

TABLE A-1
SMALLEST POTENTIALLY LETHAL FRAGMENTS FOR AIRCRAFT

Event	Fragment Mass (grams)
Penetration by aluminum fragment	3.5
Penetration by steel fragment	2.0
Penetration by tungsten fragment	0.5
Engine ingestion	1.0

4.0 Debris Hazards to Ships or Boats

Falling inert debris can be hazardous to the occupants of a ship in two ways. A fragment can directly impact a person exposed on the deck, or it can penetrate the ship or boat's structure, leading to catastrophe. Protection for the former is achieved using the same approach used for other personnel. Catastrophe protection from significant damage is achieved by protecting from larger debris which can penetrate a ship's deck. Table A-2 provides a standard for this protection.

TABLE A-2
SMALLEST POTENTIALLY LETHAL FRAGMENTS FOR SHIPS

Event	Fragment Mass (kg)
Penetration by aluminum	14.0
Penetration by steel	5.0
Penetration by tungsten	0.4

GLOSSARY

ACCEPTABLE RISK

A predetermined criterion or standard for a maximum risk ceiling which permits the evaluation of cost, national priority interests, and number of tests to be conducted.

COLLECTIVE RISK

The total risk to an exposed population; the expected total number of individuals who will be fatalities. Defined as Expected Fatalities. Collective risk is specified as either a per mission or per year value.

DEBRIS IMPACT HAZARD

The potential for injury or death resulting from the impact of falling debris. (Separate from explosive or toxic debris hazard.)

EXPECTED FATALITIES (E_F)

The expected number of individuals who will be fatalities. Used to define Collective Risk. This risk is expressed with the following notation: 1E-7 = 10^{-7} = 1 in ten million.

GENERAL PUBLIC

All people not declared mission essential. This includes the public plus range personnel not essential to a mission, visitors, press, and personnel/dependents living on the base/facility.

HAZARD

Any real or potential condition that can cause injury, illness, or death of personnel, or damage to or loss of equipment or property.

HAZARD AREA

A geographical or geometrical surface area that is susceptible to a hazard from a planned event or unplanned malfunction.

HAZARD VOLUME

A geographical or geometrical volume of airspace that is susceptible to a hazard from a planned event or unplanned malfunction.

INDIVIDUAL RISK

The risk to a single person.

MISSION ESSENTIAL

Those personnel, aircraft, and ships whose activities are directly relevant to the mission or are declared essential by the safety decision making authority.

PROBABILITY OF FATALITY (P_F)

The likelihood that a person or persons will die from a hazardous event. This risk is expressed with the following notation: 1E-7 = 10^{-7} = 1 in ten million.

RISK

A measure that considers both the probability of occurrence and the consequence of a hazard. For this standard, risk is expressed in terms of probability of fatality and expected fatalities.